(54) Title: MASSIVELY-PARALLEL DIRECT OUTPUT PROCESSOR ARRAY
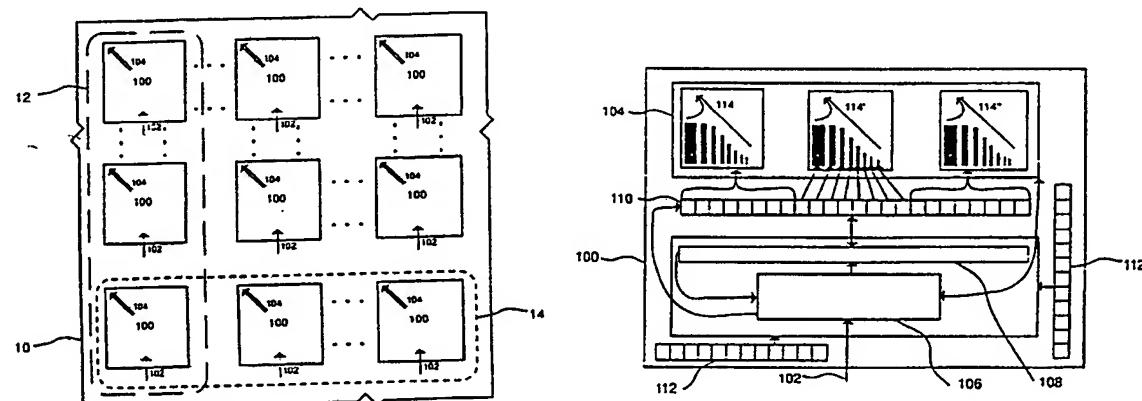
(57) Abstract

A massively parallel data processing system consisting of an array of closely spaced cells where each cell has direct output means as well as means for processing, memory and input. The data processing system according to the present invention overcomes the Von-Neuman bottleneck of uniprocessor architectures, the I/O and memory bottlenecks that plague parallel processors, and the input bandwidth bottleneck of high-resolution displays.

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MASSIVELY-PARALLEL DIRECT OUTPUT PROCESSOR ARRAY

TECHNICAL FIELD

5   The present invention relates to improvements in data processing systems. More particularly, the invention is directed to a massively parallel data processing system containing an array of closely spaced cells where each cell has direct output means as well as means for input, processing

10   and memory.

BACKGROUND ART

Parallel computer systems are well known in the art. IBM's 3084 and 3090 mainframe

15   computers, for example, use parallel processors sharing a common memory. While such shared memory parallel systems do remove the Von-Neuman single processor bottleneck, the funnelling of memory access from all the processors through a single data

20   path rapidly reduces the effectiveness of adding more processors. Parallel systems that overcome this bottleneck through the addition of local memory are also known in the art. U.S. Patent 5,056,000, for example, discloses a system using both local and

25   shared memory, and U.S. Patent 4,591,981 discloses a local memory system where each "local memory processor" is made up of a number of smaller processors sharing that "local" memory. While in these systems each local memory processor has its

30   own local input and output, that input and output is done through external devices. This necessitates having complex connections between the processors and external devices, which rapidly increases the cost and complexity of the system as the number of

35   processors is increased.

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Massively parallel computer systems are
also known in the art. U.S. Patents 4,622,632,
4,720,780,   4,873,626,   4,905,145,   4,985,832,
4,979,096, 4,942,517 and 5,058,001, for instance,
5   disclose examples of systems comprising arrays of
processors where each processor has its own memory.
While these systems do remove the Von-Neuman single
processor bottleneck and the multi-processor memory
bottleneck for massively parallel applications, the
10 output of the processors is still gathered together
and funneled through a single data path to reach a
given external output device. This creates an
output bottleneck that limits the usefulness of such
systems for output-intensive tasks, and the reliance
15 on connections to external input and output devices
increases the size, cost and complexity of the
overall systems.

Even massively parallel computer systems
where separate sets of processors have separate
20 paths to I/O devices, such as those disclosed in
U.S. Patents 4,591,980, 4,933,836 and 4,942,517 and
Thinking Machines Corp.'s Connections Machine CM-5,
rely on connections to external devices for their
input and output. Having each processor set
25 connected to an external I/O device also
necessitates having a multitude of connections
between the processor array and the external
devices, thus greatly increasing the overall size,
cost and complexity of the system. Furthermore,
30 output from multiple processor sets to a single
output device, such as an optical display, is still
gathered together and funneled through a single data
path to reach that device. This creates an output
bottleneck that limits the usefulness of such
35 systems for display-intensive tasks.

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Input arrays are also known in the art. State-of-the-art video cameras, for example, use arrays of charge-coupled devices (CCD's) to gather parallel optical inputs into a single data stream.

5   Combining a direct input array with a digital array processor is disclosed in U.S. Patent 4,908,751, and is mentioned as an alternative input means in U.S. Patent 4,709,327. Direct input arrays that do analog processing of the incoming data have been

10   pioneered by Carver Mead, et al, (Scientific American, May 1991). While such direct-input/processor arrays do eliminate the input bottleneck to the processor array, these array elements lack direct output means and hence do not

15   overcome the output bottleneck. Reliance on connections to external output devices also increases the size, cost and complexity of the overall systems.

Output arrays where each output element

20   has its own transistor are also known in the art and have been commercialized for flat-panel displays, and some color displays use display elements with one transistor for each color. Since the limited "processing power" associated with each output

25   element cannot add or subtract or edit-and-pass-on a data stream, such display elements can do no data decompression or other processing, and thus the output array still requires a single uncompressed data stream, creating a band-width bottleneck as

30   array size increases.

Portable computer systems are also known in the art. Smaller and smaller systems are being introduced every year, but the most compact systems suffer from extremely limited processing power,

35   cramped keyboards, and limited battery life.

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Traditional system assembly techniques assemble
systems from many separate pieces, which leads to
inefficient use of space. Current processor
architectures use much of the area of each processor
5   chip with wiring for long distance communication.
Furthermore, lithography errors limit the size of
processor and memory chips so many separate chips
must be used in a system. Processor chips and
memory chips are produced on separate thin semi-
10 conductor wafers, and these wafers are diced into
their component chips of which a number then are
encapsulated in bulky packages and affixed to even
bulkier printed circuit boards. These boards are
then connected to separate external devices for
15 input and output, creating systems many orders of
magnitude   bigger   than   the   component   chips
themselves.
              Integrated   circuits   fabricated   from
amorphous   silicon,   as   opposed   to   crystalline
20 silicon, are also known in the state of the art.
Amorphous silicon, though, is far less consistent a
substrate, making it far more difficult to fabricate
super-miniature components, and larger components
are slower as well as bulkier than smaller ones.
25 Since processor speed is the main bottleneck in the
uni-processor computers that dominate the computer
world, and since information gathering speed is a
growing   bottleneck,   in   the   massively   parallel
systems that are trying to replace them, the slower
30 amorphous silicon integrated circuits have not been
competitive with crystalline silicon in spite of
their lower per-circuit fabrication costs.

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DISCLOSURE OF THE INVENTION

It is therefore one object of the present invention to provide an ultra-high-resolution display containing an array of closely spaced cells
5   where each cell has optical direct output means, input means, and memory and processing means just sufficient to extract a datum from a compressed data stream and to transmit that datum through the direct output means, thus maximizing the number of cells
10 that can be fabricated in a given area.

It is another object of the present invention to overcome the drawbacks in current parallel processing systems by providing a massively parallel data processing system containing an array
15 of closely spaced cells where each cell has direct output means, input means, and means for sufficient memory and processing to perform general data processing, allowing the array to handle a wide range of parallel processing tasks without
20 processor, memory or output bottlenecks.

It is another object of the present invention to provide a massively parallel data processing system that minimizes the distances between input, output, memory and processing means,
25 allowing lower voltages to be used and less power to be consumed during operation.

It is another object of the present invention to provide an array of closely spaced cells where each cell has direct input means, direct
30 output means and means for memory and processing, allowing the array to communicate with external devices without physical connections to those devices.

It is another object of the present
35 invention to provide a data processing system

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containing an array of closely spaced cells interconnected with spare cells in a network that is highly tolerant of defective cells, allowing large arrays to be fabricated as single units with high
5   production yields in spite of defective cells.

It is another object of the present invention to provide a data processing architecture that maximizes system speed relative to component speed, thereby making practical the fabrication of
10   components from lower-cost, but slower amorphous silicon.

It is another object of the present invention to provide a data processing architecture that simplifies the implementation of continuous
15   manufacturing processes through the at-least-linear replication of all complex components.

It is a further object of the present invention to provide a method for implementing any of the aforementioned objects of the present
20   invention in single thin sheet.

In accordance with one aspect of the invention, there is thus provided an apparatus containing an array of closely spaced cells, each cell having access to a global input and having
25   direct optical output means as well as minimal memory and processing means, allowing the array to receive, decompress and display data transmitted by another apparatus, such as a computer, a TV station or a VCR.

30   In accordance with another aspect of the invention, there is thus provided an apparatus containing an array of closely spaced cells, each cell having means for communication with neighboring cells as well as direct optical output means and
35   minimal memory and processing means, allowing the

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array to receive, decompress and display a large
number of parallel input streams transmitted by
another apparatus such as a computer or a VCR, and
allowing all array cells to be logically identical
5   and to be produced with identical lithographic
patterns.

The present invention also provides, in
another aspect, a system containing an array of
closely spaced cells, each cell having its own
10 direct input means and direct output means as well
as means for memory, means for processing and means
for communication with neighboring cells, each cell
being, in short, a complete miniature data
processing system in its own right, as well as being
15 part of a larger network, providing a massively
parallel data processing system that overcomes the
I/O and memory bottlenecks that plague parallel
processors as well as the Von-Neuman bottleneck of
single processor architectures, and eliminating
20 physical interconnections between the
processor/memory array and external input and output
devices.

In accordance with still another aspect of
the invention, there is thus provided a system
25 containing an array of closely spaced cells, each
cell having direct input means and direct output
means as well as means for memory, means for
processing and means for communication with
neighboring cells, where all cells are identical in
30 logical characteristics and can be produced with
identical lithographic patterns, simplifying the
fabrication of the array with continuous linear
production techniques.

In accordance with still another aspect of
35 the invention, there is thus provided a system

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comprising an array of closely spaced cells, each
cell having multiple direct output means and
sufficient memory and processing capabilities to
simulate several smaller cells each with direct
5   output means, increasing the output resolution of
the array relative to the cell density.

In accordance with still another aspect of
the invention, there is thus provided a system
comprising an array of closely spaced cells, each
10   cell having direct output means, means for memory
and means for processing, interconnected with spare
cells in a manner such that one or more spare cells
can replace the functions of any defective cell.

The present invention also provides, in
15   another aspect thereof, a method for producing any
of the above arrays of closely spaced cells where
the entire array is fabricated as a single thin
sheet.

By the expression "massively parallel" as
20   used herein is meant a problem, a task, or a system
with at least 1000 parallel elements.

By the expression "array" as used herein
is meant elements arranged in a two dimensional
pattern or as the surface of a three dimensional
25   shape.

By the expression "closely spaced cells"
as used herein is meant that the average center-to-
center distance between neighboring cells is less
than one centimeter.

30   By the expression "direct output means" as
used herein is meant means for a given cell to send
an output signal to a device outside the array (such
as a human eye) without that output signal being
relayed through a neighboring cell, through a

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physical carrier common to the cells, or through a separate external output device.

By the expression "direct input means" as used herein is meant means for a given cell to receive an input signal from a device outside the array without that input signal being relayed through a neighboring cell, through a physical carrier common to the cells, or through a separate external input device.

By the expression "global input" as used herein is meant means for an individual cell to pick up an input signal from a physical carrier common to the cells, such as a global data bus.

By the expression "external output device" as used herein is meant an output device fabricated as a separate physical entity from the cell array.

By the expression "external input device" as used herein is meant an input device fabricated as a separate physical entity from the cell array.

By the expression "means for communication with neighboring cells" as used herein is meant input means to receive a signal from at least one neighboring cell and output means to send a signal to at least one other neighboring cell without the signals being related through a global data bus or through an external device.

By the expression "thin sheet" is meant a sheet whose total thickness is less than 1 centimeter.

The expression "could be produced with identical lithographic patterns" is used to solely describe the similarity of the structures and is not to be construed as limiting the invention to embodiments produced with lithography.

BRIEF DESCRIPTION OF DRAWINGS

These and other objects, features and
advantages of the invention will be more readily
apparent from the following detailed description of
5   the preferred embodiments of the invention in which:

FIGURE 1A is a functional depiction of an
array of direct output data-
decompression cells in accord-
ance with the invention, and
10   FIGURE 1B is a functional
depiction of one of the cells of
FIGURE 1A:

FIGURE 2A is a functional depiction of an
array of direct output data-
15   decompression cells where the
cells use neighbor-to-neighbor
communication instead of cell
addresses and a global input,
and FIGURE 2B is a functional
20   depiction of one of the cells of
FIGURE 2A;

FIGURE 3 is a functional depiction of one
direct output processing cell of
a massively parallel direct
25   output data processing array in
accordance with the invention;

FIGURE 4A is a functional depiction of one
direct output processing cell
where the cell has means for
30   communication with neighboring
cells and FIGURE 4B is a
functional depiction of an array
of direct output processing cell
with a functional depiction of
35   the communication inter-

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connections between neighboring
cells;

FIGURE 5   is a functional depiction of one
processing cell with several
kinds of direct input and direct
output;

FIGURE 6A   is a geometric depiction of an
array of processing cells with
means for any of three spare
cells to replace any defective
cell;

FIGURE 6B   is a geometric depiction of an
array of processing cells with
means for any of two spare cells
to replace any defective cell;

FIGURE 6C   is a geometric depiction of an
array of processing cells with
means for spare cells to control
the direct inputs and outputs of
cells that they replace;

FIGURE 7   is a geometric depiction of an
array of direct I/O processing
cells fabricated as a thin sheet
composed of series of thin
layers;

FIGURE 8   is a functional depiction of one
direct input and direct output
processing cell with communi-
cation with neighboring cells;
and

FIGURE 9   is a geometric depiction of an
array of processing cells using
their direct inputs and outputs
to communicate with an external
device.

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DESCRIPTION OF PREFERRED EMBODIMENTS

Conventions used in the drawings:

        A single lined arrow is used to represent
input to or output from a cell from or to another
5   element of the array,

        A double lined arrow is used to represent
direct input to or output from a cell,

        A triple lined arrow is used to represent
input to or output from a cell through a physical
10 connection to an external device,

        A dotted lined arrow is used to represent
input to or output from a cell spare cell to the
direct input and output means of a cell whose
functions it replaces, and

15   A double headed arrow is used to represent
a bi-directional input/output path.

                Ultra-High Resolution Displays

        Traditional output arrays use output
elements that contain no processing power of their
20 own, but merely transmit preprocessed data. As the
array size (resolution) and scan rate increase, this
puts more and more of a burden on the central
processing unit and its output data path. Many
high-resolution systems use specialized graphics
25 processors to relieve the main CPU of as much as
possible of this task. While this does indeed free
up the CPU by shifting the problem to a faster and
less expensive processor, the increased speed
further intensifies the pressure on the output data
30 path bottleneck. Adding a specialized graphics
processor also increases the size, complexity and
cost of the overall system.

        Accordingly, the compressed-output-data
architecture according to one embodiment of the
35 present invention as shown in FIGURES 1A and 1B

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overcomes this bottleneck with an ultra-high
resolution display containing an array 10 of output
cells 100 where each output cell contains sufficient
processing power to extract its output data from the
5   compressed data stream. Each array cell 100 in this
embodiment contains a global input 102, optical
direct output means 104, a count register 110, the
negative of its cell address (in two's complement
form) 112 and 112', and the processing power to add
10 a number from the input 102 to the count register
110 and check the result for a register overflow.
Types of optical direct output means 104 include,
but are not limited to, light emitting diodes
(LEDs), liquid crystal display elements (LCDs),
15 semi-conductor lasers and ultra-miniature cathode
ray tubes (CRTs). Because each cell in this
embodiment has means for direct optical output, the
array of cells creates a light pattern on its
surface, and thus functions as an optical display.
20 An example of a data compression scheme and
sufficient processing power to decompress it is to
provide each cell with a four-instruction decoder
106. Two-bit opcodes are used to represent the four
different instructions - "This cell's output becomes
25 ...(COB)", "Next N Cells' output become ... (NCOB)",
"Next N cells' output remain unchanged (NCRU)", and
"Reset (RES)". When the decoder 106 receives the
RES (reset) opcode, it copies its negative cell
address 112 and 112' to the count register 110.
30 Then as each opcode is encountered the adder 108
adds the number of cells the instruction controls (N
for NCOB and NCRU or 1 for COB) to the count
register 110. When the count register overflows,
the cell uses the opcode that caused the overflow to
35 determine the new output value for the direct output

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means 104.   For NCRU, the cell's direct output
remains unchanged.   For COB or NCOB, the cell adopts
the data portion of the instruction for its new
output data.   The compression principle is similar
5   to what current FAX machines use for data
transmission except that the compression op-codes·
have been extended to cover changing displays as
well as static displays.   The datum that the cell
can display can range, depending on the
10   implementation, from one-bit black and white to
multibit grayscales to full color output.   In a
typical implementation the datum might be a 24-bit
word where 8 bits each refer to the relative
intensities of red, green and blue direct outputs
15   114, 114' and 114".   A minimum-processing-power
implementation can provide each cell with 8 direct
outputs for each color with relative intensities of
1, 2, 4, 8, 16, 32, 64 and 128, corresponding to the
intensity bits for that color.   This uses the
20   intensity bits directly as flags instead of
processing them as a number.   With the best
lithography now used in production (December 1991),
a density of over 100,000 cells per square inch is
possible, giving such an array resolution several
25   times better than and color reproduction far better
than a glossy magazine photo.   While a multi-
million-cell array can be fit onto an 8-inch silicon
wafer, such displays will be small, fragile, and
expensive until continuous production techniques are
30   used.   These should increase size and reduce cost to
comparable to today's CRT displays, but with a
display quality several orders of magnitude better.
With slightly more processing power per cell, an 8
bit intensity multiplier can be added to each datum
35   to form a 32 bit word. The cell's processing can be

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the same except that the cell's entire set of direct
outputs is switched on and off at a constant rate of
at least 60 times per second, with the length of the
"on" phase being proportional to the 8 bit intensity
5   multiplier. This gives the display a far greater
range of intensity and simplifies the adjustment of
output brightness to compensate for changes in
ambient light intensity. For continuous linear
production, each cell can be fabricated using
10   identical lithographic patterns, with the exception
of the cell's address. Each cell contains an
address region with 12 bits each for its X and Y
array coordinates 112 and 112'. This makes address
pattern 112 constant for every cell in a given
15   column 12 (the direction of production), so these
addresses can be formed with a constant pattern as
part of the continuous production process. Because
the other address pattern is constant for every cell
in a given cell row 14 in a perpendicular direction,
20   address pattern 112' is produced as a constant set
of address lines which is then customized in a
separate post-continuous-production finishing step
using a constant pattern and motion perpendicular
the   original   direction   of   production.
25   Customization can be performed for example, by using
a linear array of lasers to selectively cut address
lines in address regions 112'.

Even with data compression some output-
intensive tasks will encounter a bottleneck in the
30   global input to the cells, especially in extremely
large   arrays.   The   compressed-data-output
architecture according to another embodiment of the
present invention as shown in FIGURES 2A and 2B
therefore replaces the global inputs 102 with means
35   for communication with neighboring cells 202. The

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array 20 is composed of rows of direct output cells
200 where each cell can receive information from the
cell "before" it, process the information received
and send the processed information to the next cell.

5   Adder 208 and count register 210 can be identical to
adder 108 and count register 110 of the previous
embodiment. Decoder 206 replaces decoder 106 for
handling the decompression opcodes. As in the
previous embodiment, there are many compression

10   schemes that can be used. The scheme used in the
previous example has been used here for consistency.
While the compression opcodes are the same as those
used in the previous embodiment, the processing is
quite different. A reset (RES) opcode is always

15   passed on to the next cell. After a reset opcode
each cell 200 looks at the first opcode it receives.
For COB and NCOB, it takes the immediately following
data as its new value for direct output means 204.
For COB it then removes the opcode and data from the

20   stream, while for NCOB it decrements the cell
control count N and only if N is zero does it remove
the opcode and data from the stream. For NCRU, the
cell's direct output means 204 remains unchanged,
and the cell decrements the counter N and if N is

25   zero it removes the opcode and data from the stream.
The processing of the output datum that the cell
receives can be identical to the previous
embodiment, but this embodiment has several
advantages. A separate input 22 is used for each

30   row of cells, which removes the potential input
bottleneck, and no addresses are needed by the
cells, allowing all cells to be identical and
eliminating post-continuous-production customizing.
The disadvantage is that the connection to the data

35   source becomes far more complex, consisting of many

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separate inputs 22, which can use either direct or
external input means.

Massively Parallel Data Processing Architecture

Traditional computer architectures use
5   separate devices for input, processing, memory and
output. While this scheme is efficient when a
single or small set of fast and expensive processors
is performing compute-intensive operations on serial
processing problems, limitations arise as the number
10   of processors is increased to handle highly parallel
problems. After the Von-Neuman single processor
bottleneck is removed with multiple processors,
memory access bottlenecks dominate next. Most
massively parallel architectures solve this by
15   having local memory associated with each processor.
For compute-intensive problems this works well for
implementations of up to tens of thousands of
processors, such as the Connections Machine of
Hillis, et al. Many parallel problems, however,
20   (such as fluid-flow simulations), are output
intensive as well as compute intensive, and as the
number of processors increases the gathering and
coordination of the output of the processors for
transmission to an external device becomes a
25   limiting factor. Increases in output resolution,
such as the previously described compressed-output-
data embodiments of the present invention, further
increase the amount of output that must be gathered
and coordinated.
30   Accordingly, the massively parallel data
processing architecture aspect of the present
invention as shown in FIGURE 3 removes this
bottleneck by providing an array of closely spaced
cells 300 where each cell has direct output means
35   304 as well as means for memory 316, means for

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processing 320 and means for input 302. While
processor 320 be more complex than a RISC
microprocessor extremely simple processors are
usually more suitable with the array architecture of
5   the present invention. At a minimum each processor
320 should contain an instruction decoder 306, an
arithmetic/logical unit 308, at least one register
310, and a memory fetch/store unit 312. By far the
most useful sort of direct output means 304 is
10   optical output means, although direct sonic and
infra-red output will have uses as well. While it
is possible to have the direct output means 304
placed between the cells and shared by neighboring
cells (in a manner similar to the shared memories of
15   U.S. Patents 4,720,780 and 4,855,903), providing
each cell 300 with its own direct output means 304
can produce better performance with simpler
lithography. Providing each array cell 300 with its
own direct output means 304 is the same as providing
20   each output cell of previously described compressed-
output-data architecture embodiments of the present
invention with sufficient processing power for the
array to process parallel problems as well as to
display the results. A processor/output array so
25   designed avoids the complexity of having a multitude
of connections between the processor array and
external output devices as well as allowing the
array to be expanded indefinitely without an output
bottleneck.
30   While an array of cellular processing
elements which communicate solely through a global
data bus is efficient at solving action-at-a-
distance parallel computing problems such as
galactic evolution, where every star exerts a
35   gravitational pull on every other, most parallel

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processing problems, such as fluid dynamics, involve
neighbor-to-neighbor interactions.   A preferred
embodiment of the massively parallel data processing
architecture according to the present invention as
5   shown in FIGURES 4A and 4B therefore provides an
array 40 of closely spaced cells 400 where each cell·
has means 418 for communication with neighboring
cells in addition to means 402 for input and output
to a global data bus.   This combination is simpler
10 and is more efficient for most parallel processing
problems than the hypercube connectivity used in the
Connection Machines.   Means 418 for communication
between neighboring cells can be through direct
connections or through memory means placed between
15 the cells and shared by the cells in a manner
similar to the shared memories of U.S. Patents
4,720,780 and 4,855,903.   One of the simplest
systems   that   can   use   neighbor-to-neighbor
connectivity is a neural network – each cell 400
20 needs only sufficient processing and memory to
contain a connectivity value for each of its
neighbors and to be able to add up these values when
it receives signals from its neighbors, and, when
the accumulation reaches a certain value, send
25 signals to its neighbors and through the direct
output means 404, for such an array 40 to perform
useful work. While bi-directional communication 418
with two neighboring cells, one bit for a
connectivity value for each of those cells, and a
30 two bit register for adding connectivity values is
theoretically sufficient to create a neural network
in a sufficiently large array of cells, practical
considerations dictate means 418 for bi-directional
communication with at least three neighboring cells,
35 memory for a connectivity value of at least 2 bits

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for each of those cells, and an accumulation register of at least 4 bits. Further additions of memory 416 and processing power 420 make neural networks far easier to implement and enable the
5   interconnected array 40 to handle a wide range of other parallel processing tasks as well. Fluid dynamics simulations, for example, usually can be implemented with less than 64 bytes of memory 416 per cell 400, although more memory makes the job
10   significantly easier. In rectilinear arrays of cells bi-directional connectivity 148 to four neighbors is expected to be optimal in almost all cases. For fabrication with current lithographic techniques, arrays 40 that are larger than the area
15   of the fabrication masks use non-alignment-sensitive contacts 422 to connect neighboring cells across mask boundaries. This allows the use of rows or arrays of small individually aligned masks to produce large arrays as single units.

20   In a further preferred embodiment of the massively parallel data processing architecture according to the present invention as shown in FIGURES 6A, 6B and 6C, the array 60 of closely spaced cells 600 contains spare cells 600'
25   interconnected to the active cells 600 in a manner such that should any active cell prove defective, at least one spare cell can replace its functions. While this can be done by pairing a spare cell with each active cell, a far more effective way is to
30   provide a column of spare cells 600' for every two columns of active cells 600, and to interconnect the cells so that more than one spare cell can take over the functions of any given active cell. This provides an extremely error-tolerant system, which
35   is of critical importance in allowing a large array

of cells to be fabricated as a single unit. When pushing the limits of lithography it is not uncommon to average a 200 errors per 5" wafer. Under such conditions an implementation that allows any of

5 three spare cells to take over for any defective cell will increase yields of a full-wafer system with 1000 cells per square inch from near zero to over 99.99%. With a continuous linear production line producing page-sized (8 ½" x 11") systems,

10 error-tolerance will be even more critical. It may be advantageous for spare cells not to have their own direct output means, but to use the direct output means of the defective cells they replace instead, as shown in FIGURE 6C. With optical output

15 means that reflect or refract ambient light this allows the direct outputs from the active cells to cover substantially all of the surface of the array, increasing the percentage of ambient light that can be controlled, and for all direct output means it

20 keeps the direct output lined up with the cell that would normally have produced it. While this does not provide the same degree of error tolerance for direct output as for processing and memory, the control means for the cell's direct output means

25 contains relatively little function compared to the cells memory and processing means, so errors in it should be relatively rare. Means for the output control can also thus be made robust or have redundancy built in at little cost in cell area.

30 Furthermore, a defective output pixel would not be as serious for most array uses as a defective processor or memory. In arrays where the active cells do not have means for communication with neighboring cells, no other connections between

35 spare cells and active cells are needed. In arrays

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where active cells have neighbor-to-neighbor connections, however, the spare cells must be able to replace these connections as well, as shown in FIGURES 6A and 6B. The lower left corner of FIGURE
5 6A shows the interconnections between one active cell 600 and its nearest neighbor active cells in each direction. While only one active cell's connections have been shown, in an actual such array all active cells would be so connected to their
10 neighboring active cells. The center of FIGURE 6A shows the connections between one spare cell 600' in this array and all of the cells it has connections to. This spare cell can take over for any of its neighboring active cells 600, which have been marked
15 with an 'X' for clarity. Because any active cell can be taken over for by the adjacent spare cell in its own row or the row above or below it, there are three spare cells that can take over for any active cell. FIGURE 6B shows a similar scheme where either
20 of two spare cells can take over for any defective active cell. The spare cell scheme as shown in FIGURES 6A and 6B can be extended to provide still more spare cells capable of replacing any given active cell either by providing the ability for each
25 spare cell to replace more of its neighboring active cells, or, should inter-cell connectivity space be at a premium, by alternating a column of spare cells for every one column of active cells.

    In a further preferred embodiment of the
30 massively parallel data processing architecture according to the present invention as shown in FIGURE 8, each array cell 800 has both direct input means 824 and direct output means 804 as well as means for memory 816 and processing 818. Access 802
35 to a global data bus and means 818 for communication

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with neighboring cells are usually useful additions
to this embodiment as well. Useful types of direct
input means 824 include but are not limited to
optical, sonic, infra-red, and touch/proximity.
5   Having the cells equipped with both direct input
means and direct output means allows the array to
handle input intensive tasks without encountering an
input bottleneck gives the cells the ability to
interact with the outside world in a variety of
10 ways.   With optical direct output means and
touch/proximity direct input means, for example, a
portion of the array can "display" itself as a
keyboard for any language, and data can be entered
by typing on the "keys". Then, when more area is
15 required for the output, that section of the array
can "become" part of the output display. Having
both optical direct input means and optical direct
output means as shown in FIGURE 9 is also especially
preferred - input and output between the array 90
20 and separate devices 926, such as mass storage
systems or network interfaces, can then be done
through devices that are placed in proximity to the
array and communicate through the cells' direct
inputs and outputs. This allows the array to use
25 external input and output devices without physical
connections to those external devices, reducing
total system complexity, fragility and costs. Since
each cell 900 has direct optical input and output
means, this also allows arrays to communicate
30 extremely rapidly with each other when placed face
to face. In the case where the direct optical
output means are light emitting means, this also
allows the array to scan documents by emitting light
through these outputs and receiving the reflected
35 light through its direct optical inputs.

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The commercial viability and ease of acceptance of a new data processing architecture are greatly enhanced if it is compatible with existing software. With the massively parallel data
5 processing architecture disclosed in the present invention compatibility can be achieved without each cell being able to handle the hundreds of instructions of a CISC microprocessor architecture or even the dozens of instructions of a RISC
10 microprocessor architecture. If a given cell has sufficient memory and processing power to handle one instruction from the target instruction set, then a set of dozens or hundreds of cells can cooperate to emulate the entire instruction set. A further
15 preferred embodiment of the massively parallel data processing architecture of the present invention therefore includes sufficient processing power for each cell to handle any one instruction from a current RISC or CISC microprocessor architecture,
20 allowing sections of the array to be programmed to run existing software in addition to software in the array's native instruction set. Further memory is, of course, highly advantageous, with between 1024 and 4096 bytes per cell providing a good balance
25 between cell size and cell memory for arrays designed to emulate other processors. In such embodiments it is advantageous to have a local data bus connecting the set of cells that are used to emulate the more complex processor. A local data
30 bus gives each emulated processor access to the combined memories of its component cells without the overhead of multiple neighbor-to-neighbor passes and without creating a bottleneck on the global data bus. In especially preferred embodiments the size
35 of the local data bus is not predefined - cells have

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the ability to join or leave a local data bus, allowing its size to change as processing tasks change.

In a further preferred embodiment of the
5   massively parallel data processing architecture of the present invention (see FIGURE 5), each array cell 1000 is equipped with input and output means 1002 to a global data bus, means 1018 for input and output communication with each of its neighboring
10 cells in two dimensions, sufficient memory 1016 and processing power 1020 to decompress a data stream and to emulate at least any one instruction from a RISC or CISC microprocessor instruction set, full color 1004 and sonic 1032 direct output means and
15 full color 1024, capacitance touch/proximity 1030 and sonic 1034 direct input means, and means 1036 to join a local data bus. This allows the array, in conjunction with network interface devices and appropriate storage devices (which need not be
20 physically connected to the array), to function as a super high resolution TV, a super high fidelity sound system, a standard sonic and full color picture telephone, a document scanner/facsimile machine, and a voice, vision and touch activated
25 supercomputer that is upward compatible with existing software.

In exceptionally preferred embodiments of the present invention, the entire array of closely spaced cells of any of the embodiments described
30 above is fabricated as a single thin flexible sheet. This can be done, for example by fabricating the array from thin layers of amorphous silicon and metallic conductors on a thin plastic substrate. In the example shown in FIGURE 7, the array 1100 is
35 fabricated as follows: Layer 1110 is smooth sheet

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of fairly stiff plastic (LEXAN, for example) around
250 microns (10 mils) thick. For arrays where cells
have access to a global data bus, the global data
bus layer 1120 is created next by vacuum depositing
5   a 25 micron layer of aluminum, followed by a layer
of sputtered quartz or some similar insulator.
Power layer 1130 is created in a similar fashion.
For arrays with a global data bus, a small hole for
each cell is etched through the power layer to the
10   global data bus, and an insulted vertical "wire" is
deposited inside to give the cell access to the
global data bus. Next the processor/memory layer
1140 is built. A layer of amorphous silicon (or
other semiconductor material) around 50 microns
15   thick is deposited and doped through a low-
temperature doping system (such as ion implant) in a
manner similar to standard integrated circuit
fabrication. Metalized layers are used to connect
the elements in the processor/memory layer standard
20   integrated circuit chip manner (except for
connections to power and ground). Next a layer of
insulator is deposited everywhere except where
connections to the ground layer will go. The ground
layer 1150 is created in the same manner as the
25   power layer 1130. For arrays which require external
power connections, the power and ground layers have
regions left exposed at the sides of the array, to
which the appropriate connections are made. Holes
are drilled through to contacts in the
30   processor/memory layer and insulated vertical
"wires" are deposited inside these holes to give the
processor/memory layer 1140 access to the direct I/O
layer 1160. The direct I/O layer 1160 is added
next, with the direct optical outputs in a
35   fabricated in a manner similar to any of those used

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in making pixels on a flat-panel portable computer
display, the direct optical inputs fabricated in a
manner similar to that used in making a CCD input
chip, and the touch/proximity direct inputs
5 fabricated as miniature standard capacitance
touch/proximity detectors. All of these techniques
are well known in the art. The top layer 1170 is a
clear protective layer - 100 microns of LEXAN
(polycarbonate) provides scratch resistance and
10 bring the total thickness up to around 650 microns,
or .65 mm. Thus, the entire array of cells in this
implementation is a stiff but not brittle sheet
under a millimeter thick. Because systems built
this way are extremely portable, it is advantageous
15 to design all of the elements for minimal power
consumption (i.e. SRAMS instead of DRAMS). While
different orderings of the layers can be used, the
ordering chosen for this example has some important
advantages. The processor/memory layer is
20 sandwiched directly between the power and ground
layers for fast and easy access to power, which
speeds up processing and reduces power requirements.
Also, the ground layer and the global data bus layer
shield the sensitive processor/memory layer from
25 external electromagnetic interference. If the array
is equipped with sufficient photovoltaic receptor
area, a carefully designed array can be powered
entirely by ambient light, eliminating the need for
external power supplies. If each cell has its own
30 photovoltaic receptor, it should even be possible to
get rid of the power and ground layers, simplifying
production considerably.

All examples used in this patent are to be
taken as illustrative and not as limiting. As will
35 be apparent to those skilled in the art, numerous

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modifications to the examples given above may be made within the scope and spirit of the invention. While flat rectilinear arrays have been shown for simplicity, cells can be connected in triangular,

5   hexagonal, octagonal or other configurations. Such configurations need not be planar - the surface of a sphere, for example, can be covered with interconnected cells. It is also possible to use layers of cells with direct connections to input and

10 output elements on the surface, or to use three dimensional arrays of cells where only the surface cells have direct output capabilities. One way to achieve this effect with planar arrays is to have direct inputs and outputs on both faces of the array

15 so that separate arrays can be stacked into a 3-D array processor of incredible speed. It is also possible to add layers to an array that speed up long-distance cell-to-cell communication, such as by implementing the hypercube connectivity used in the

20 Connection Machine. While such additions are not expected to be cost-effective for most uses of the systems disclosed in this patent, they may prove advantageous for special applications.

Array elements in the present invention

25 are not limited to silicon, to semi-conductors in general, or even to electronics. An optical processor and memory array could be very conveniently coupled to direct optical inputs and outputs, for example. Nor are the cells' elements

30 limited to binary or even digital systems. A hybrid system where each cell had analog input and analog connections to neighbors in addition to digital processing, memory and direct output appears to be very promising for real-time vision recognition

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systems. It is also possible to have more than one
processor per cell.

        Nor are the sizes of the features used in
the examples to be taken as maxima or minima. Using
5 current lithography the architecture disclosed can
pack the power of a Cray YMP supercomputer into an
array the size of a credit card, and even smaller
arrays will prove useful, too. The architecture
will also support multi-billion-cell arrays the size
10 of a movie theater screen with equal ease.

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CLAIMS

1.   A massively parallel data processing system containing an array of closely spaced cells where each cell has input means, processing means, memory means and direct output means, where the memory and processing means are at least sufficient to extract a datum from a compressed data stream prior to transmitting that datum through the direct output means.

2.   A massively parallel data processing system as claimed in claim 1, where each cell has means for communication with neighboring cells.

3.   A massively parallel data processing system as claimed in claim 2, where each cell has means for bi-directional communication with at least three neighboring cells, memory means at least sufficient to store a value of at least two bits for each of those neighboring cells and to store a sum of at least four bits, and processing means at least sufficient to add the corresponding value to that sum when the cell receives a signal from a neighboring cell and to send a signal to the cell's neighbors and through the cell's direct output means when that sum exceeds a given value.

4.   A massively parallel data processing system as claimed in claim 2 or claim 3, where the cells are organized into columns and where all cells in a given column have identical logical characteristics and could be produced with identical lithographic patterns.

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5.   A massively parallel data processing system as claimed in claim 3, where each cell has means for multiple direct outputs and sufficient memory and processing capabilities to simulate an array of simpler cells where each cell has input means, processing means, memory means and direct output means.

6.   A massively parallel data processing system as claimed in claim 3, where each cell also has input means from and output means to a global data bus.

7.   A massively parallel data processing system as claimed in claim 3, where each cell also has sufficient memory and processing power to handle any one instruction from at least one pre-existing RISC or CISC instruction set.

8.   A massively parallel data processing system as claimed in claim 7, where each cell has means to join and leave a local data bus.

9.   A massively parallel data processing system as claimed in claim 3, where each cell has full color direct output means and full color and touch or proximity direct input means.

10.   A massively parallel data processing system as claimed in claim 9, where each cell also has sonic direct output means and sonic direct input means.

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11.   A massively parallel data processing system as claimed in claims 1, 2, 3, 4, 5, 6, 7, 8 or 9, where the array of cells is fabricated as a single thin sheet.
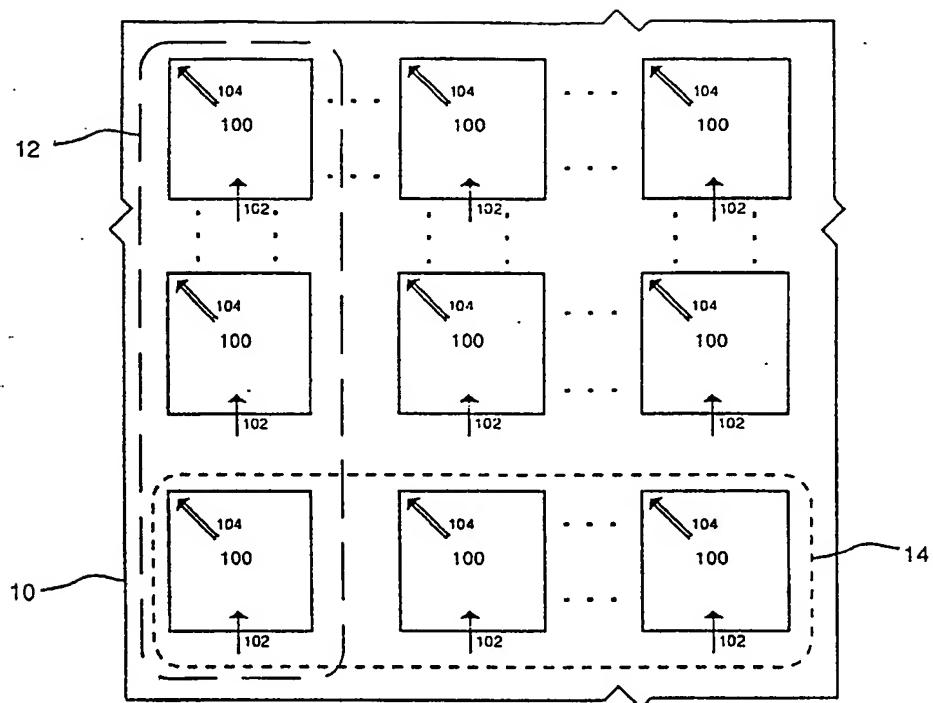
FIG. 1A
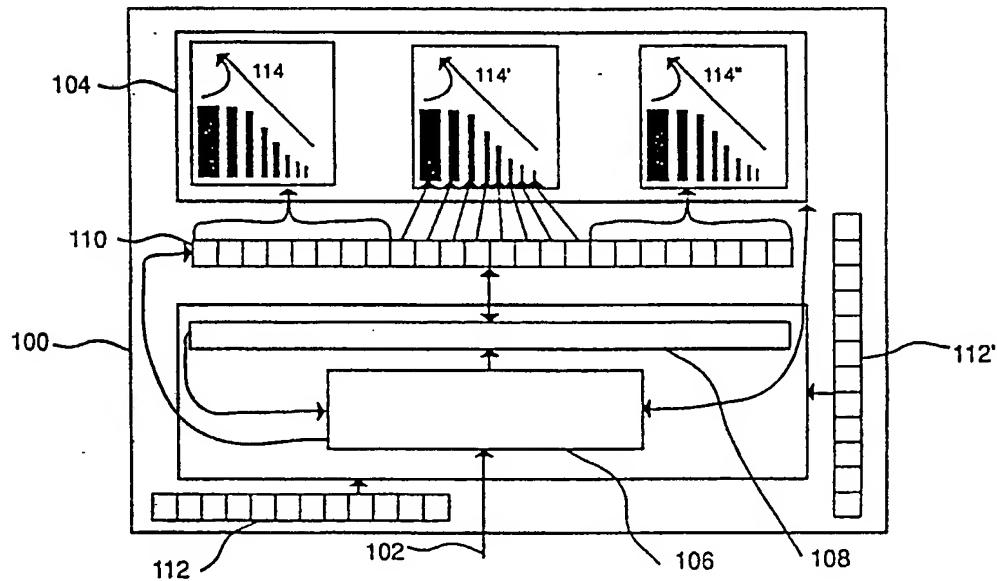
FIG. 1B
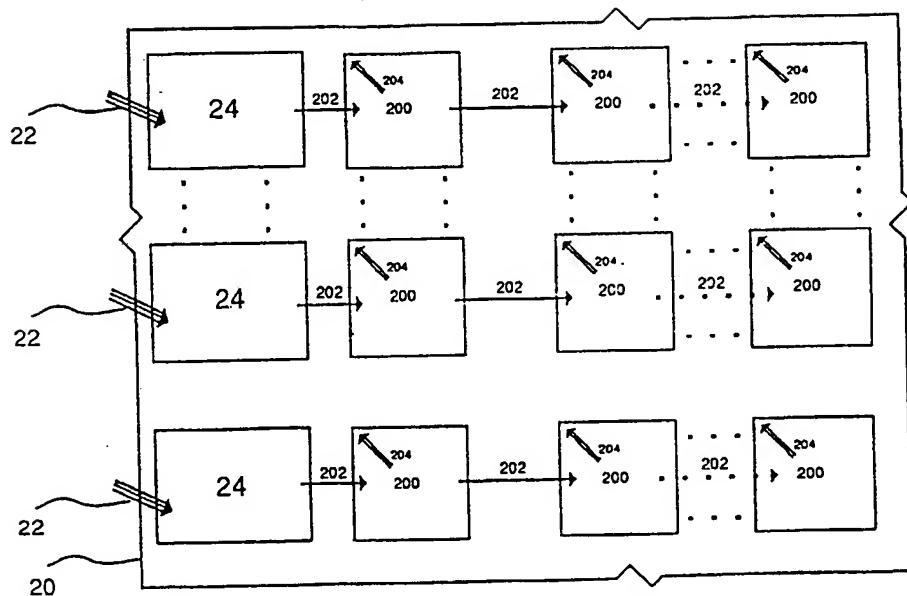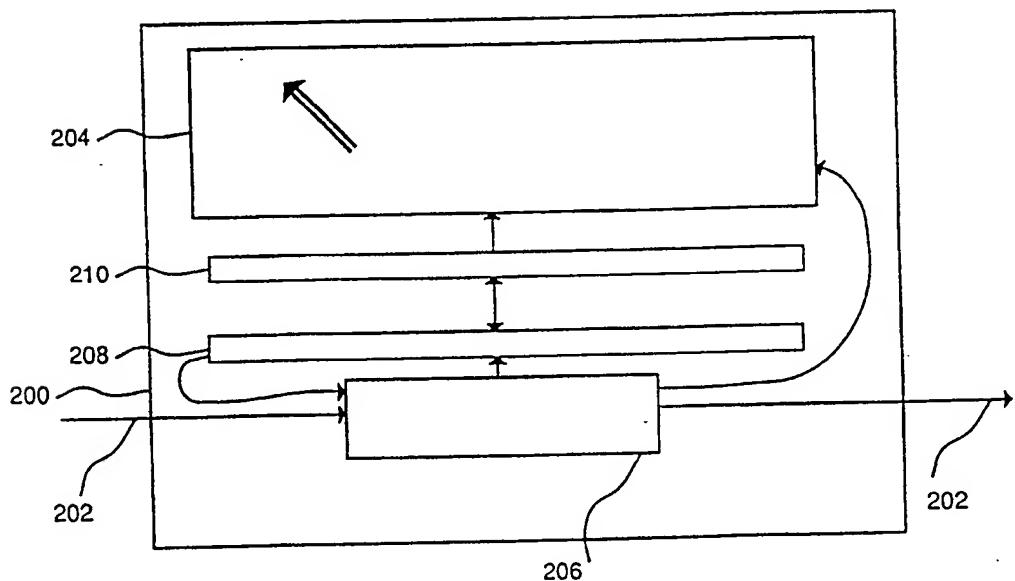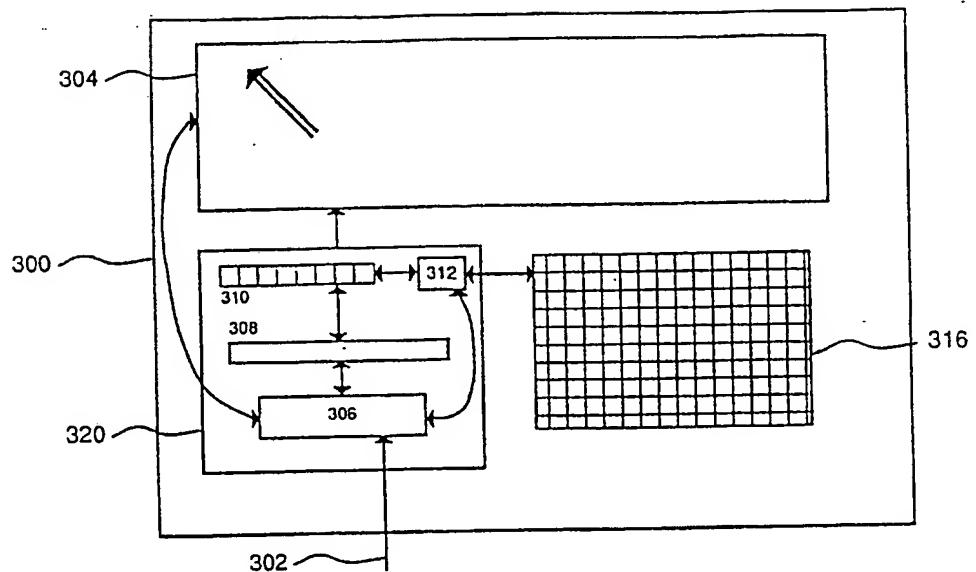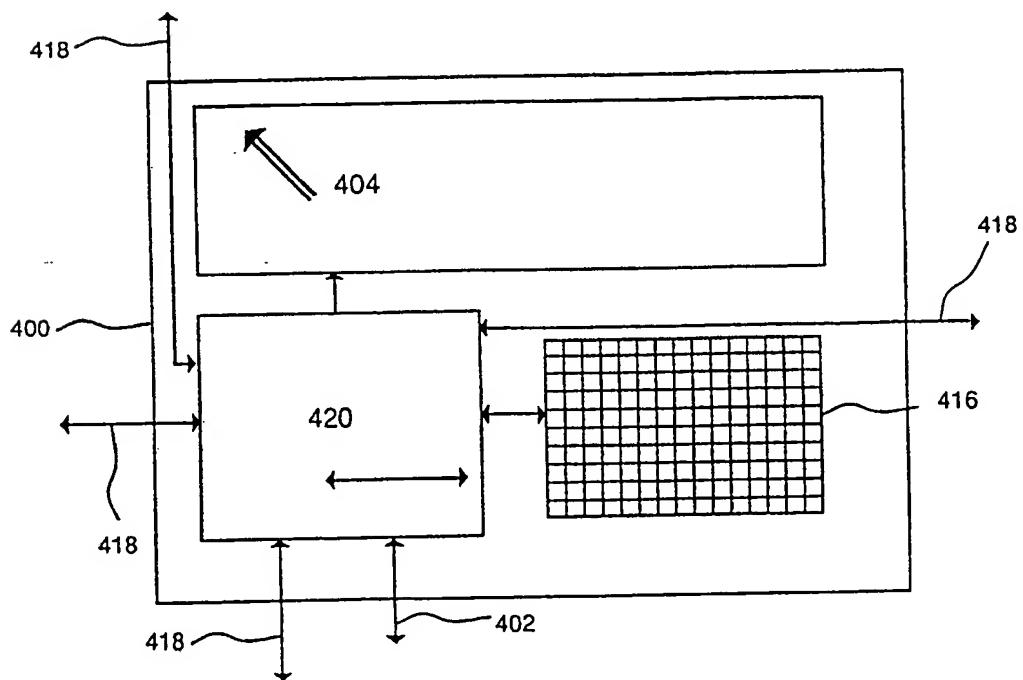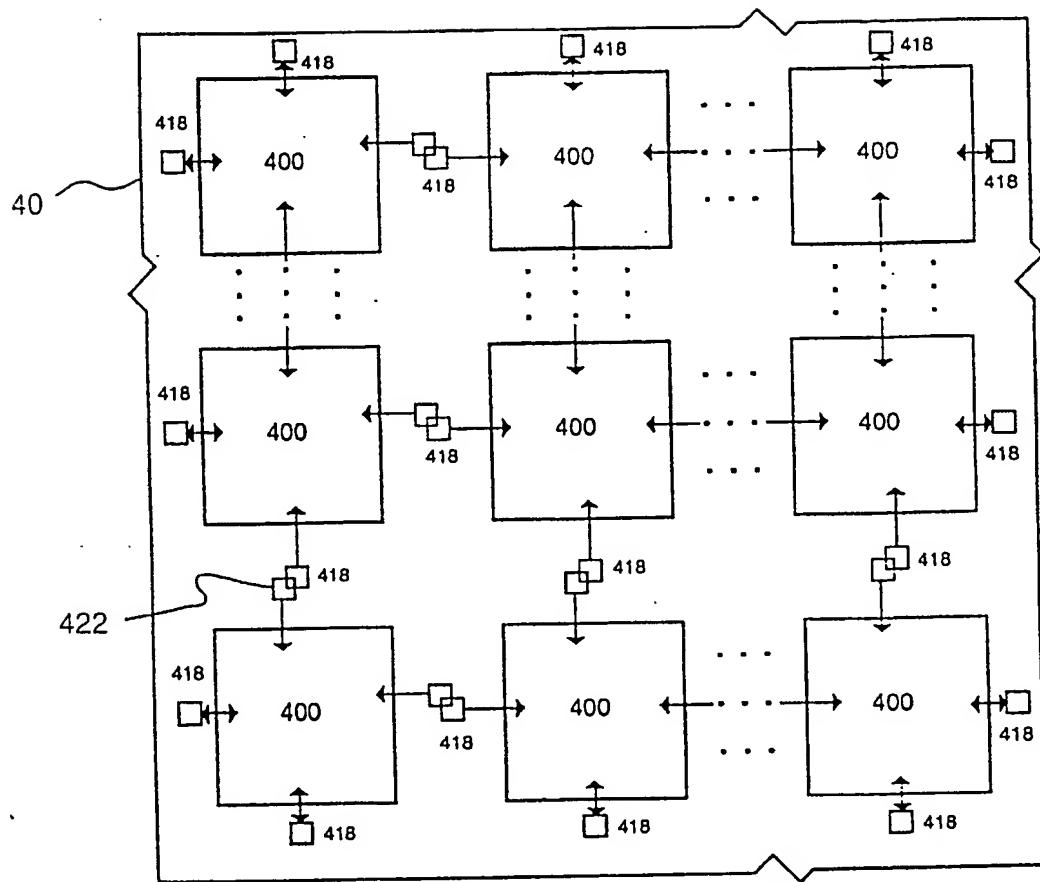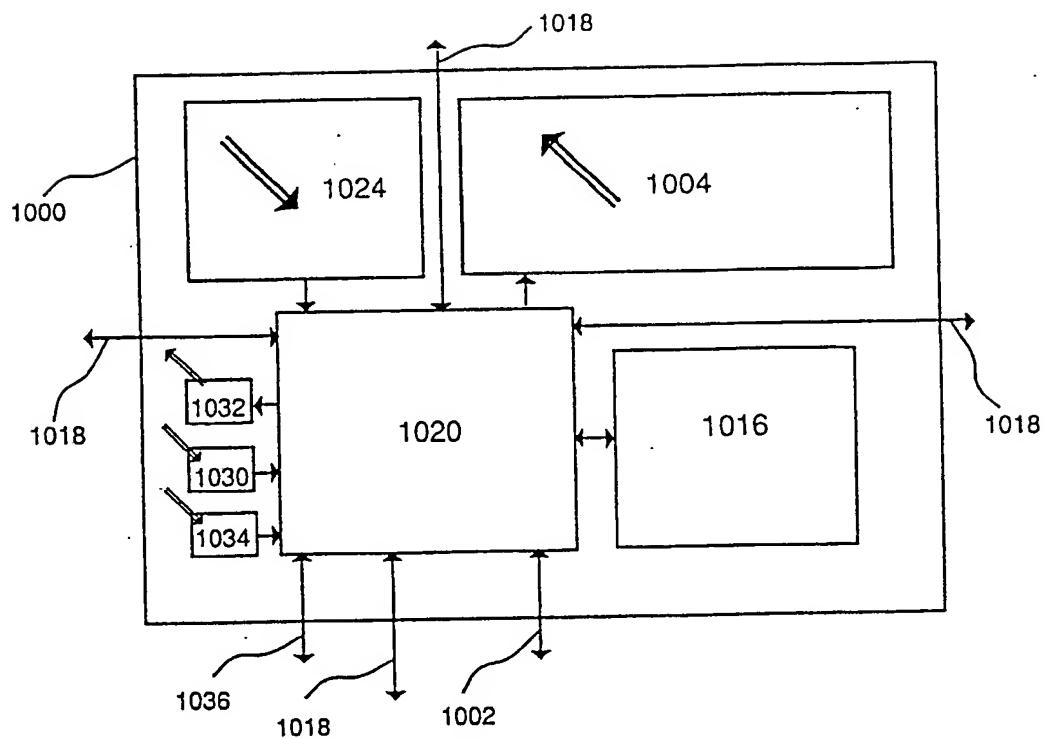
FIG. 2A

FIG. 2B

Fig. 3

Fig. 4A

FIG. 4B

$$\boxed{\mathsf{Fig}} . 5$$
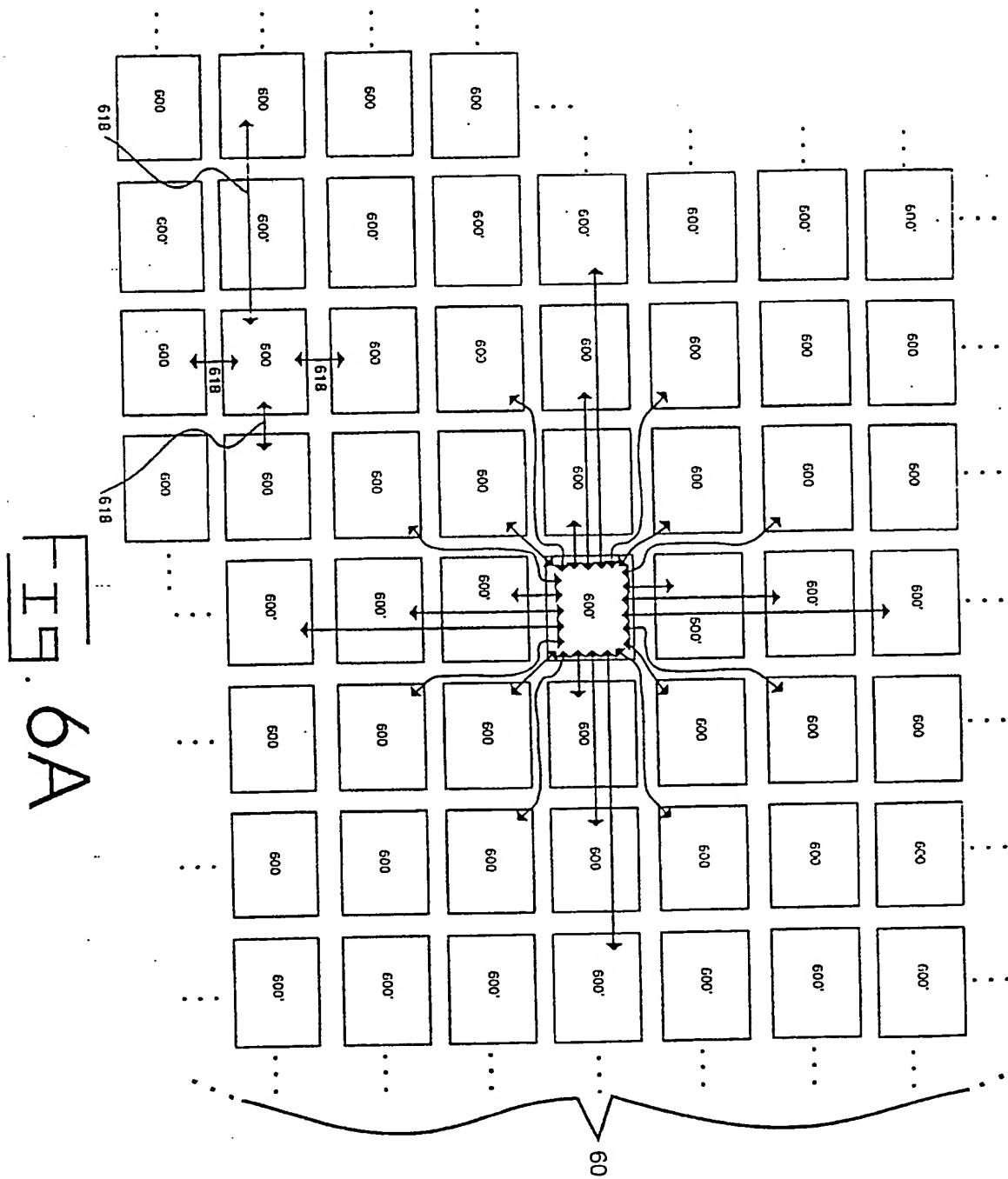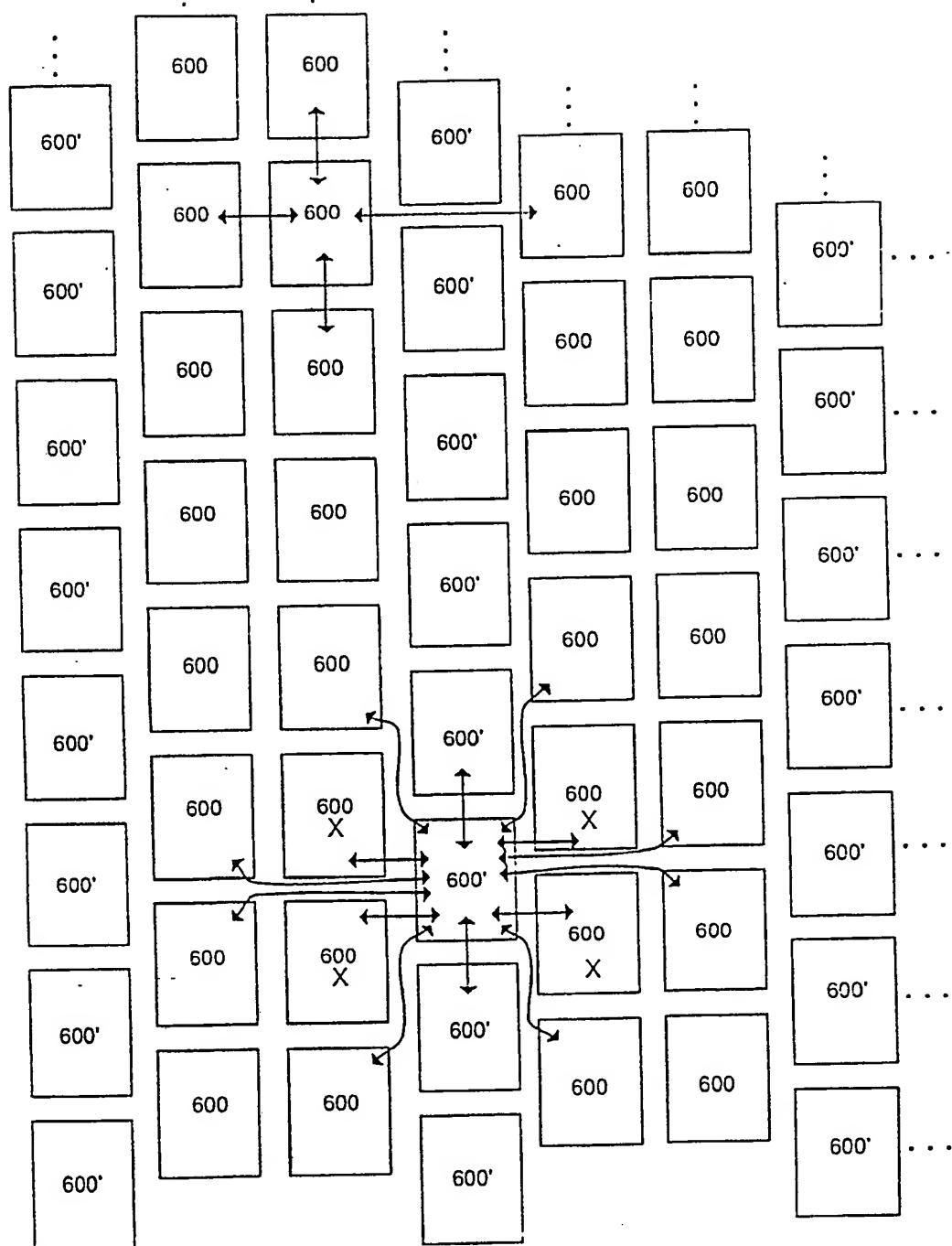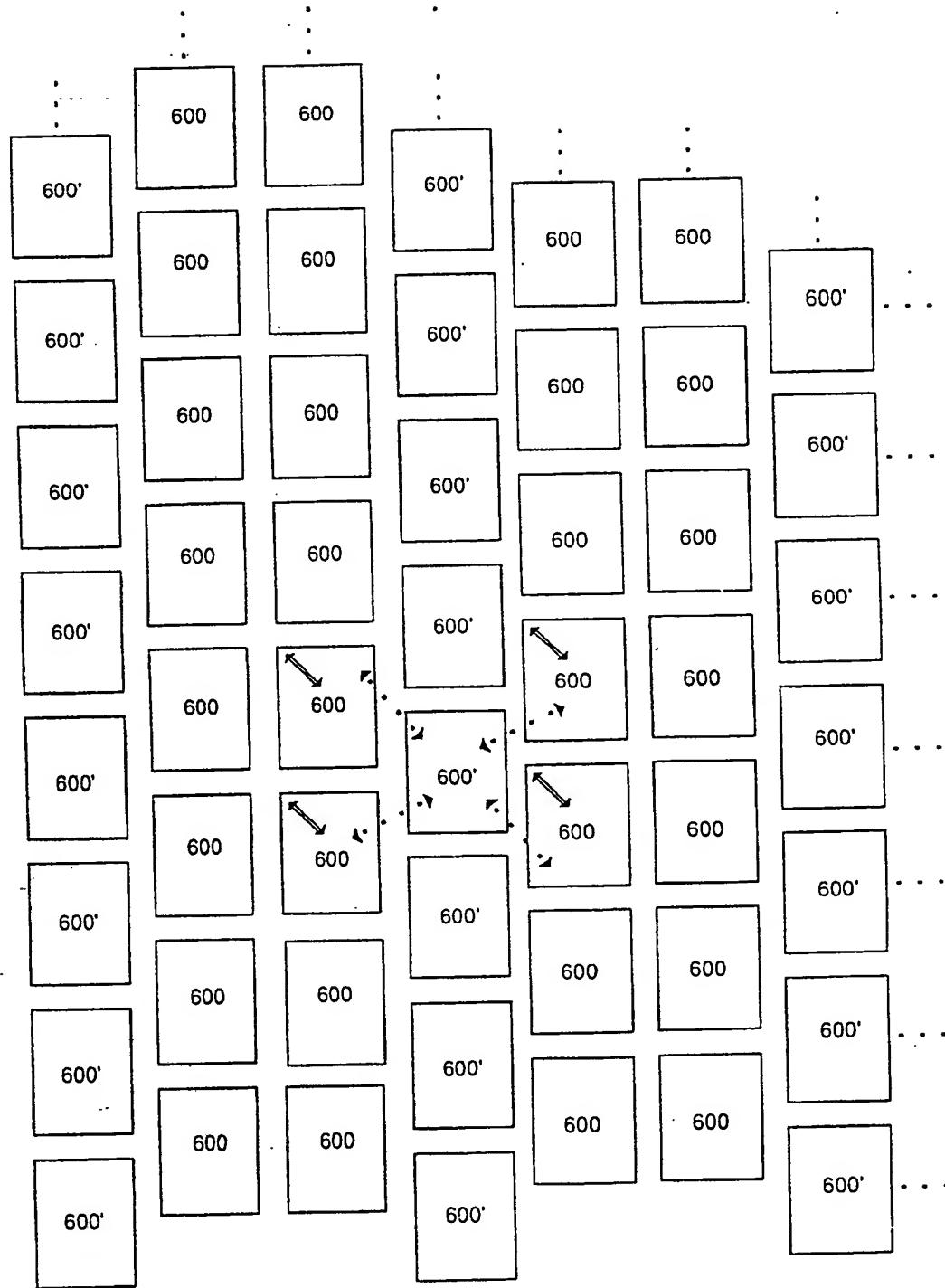
Fig. 6A

FIG. 6B

FIG. 6C

1170

1100

1160

1150

1140

1130

1120

·1110

FIЭ.7
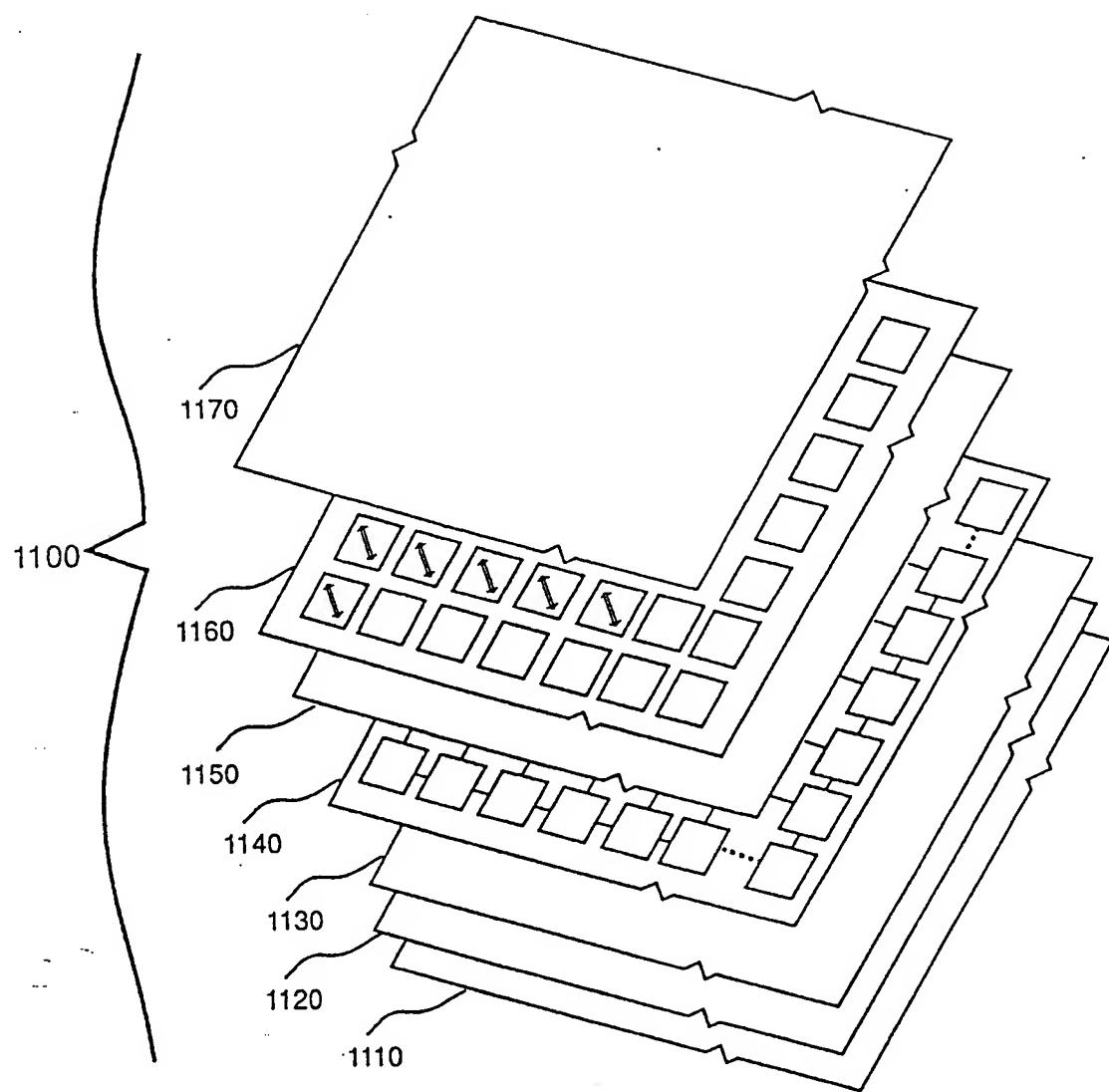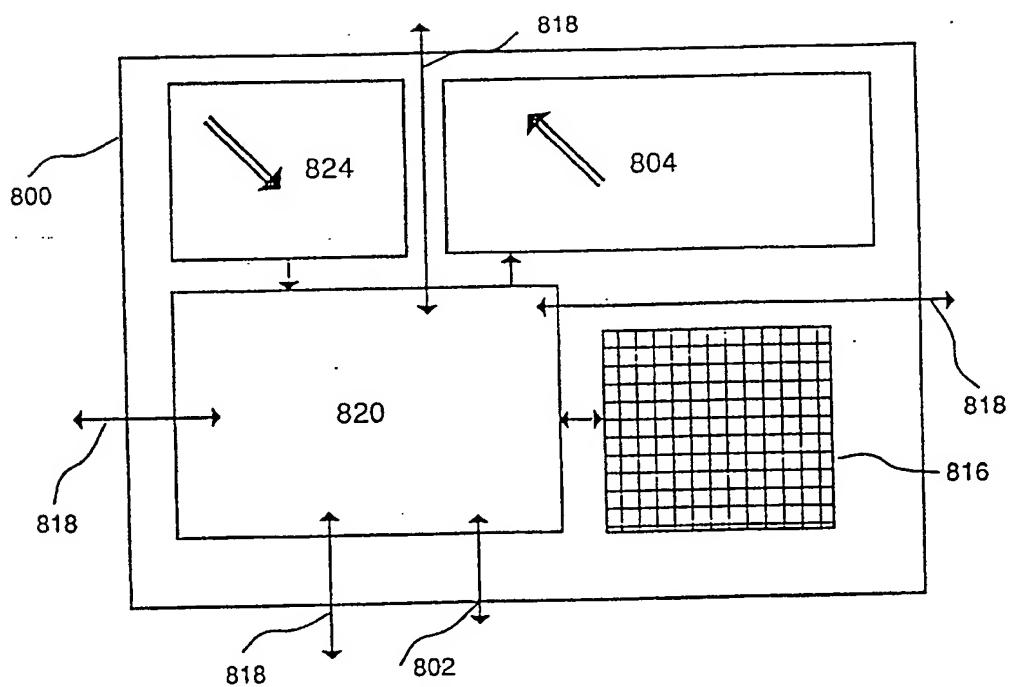
FIG. 8
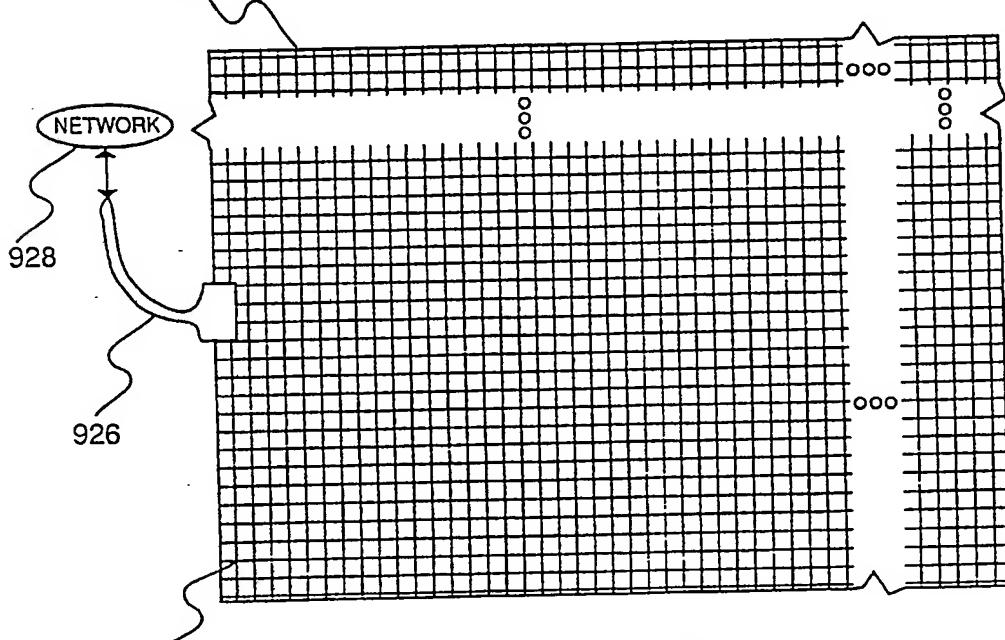
FIG. 9

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]
According to International Patent Classification (IPC) or to both National Classification and IPC
Int.Cl. 5 G06F15/80

II. FIELDS SEARCHED

Minimum Documentation Searched[7]	
Classification System	Classification Symbols
Int.Cl. 5	G06F

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category[°]	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
X	COMPUTER SYSTEMS SCIENCE AND ENGINEERING vol. 4, no. 2, April 1989, pages 107 - 114 D. J. HUNT 'AMT DAP - a processor array in a workstation environment'	1-2
A		3,4,6,7, 9,11
	see abstract see page 107, right column, line 1-3 see page 107, right column, line 15 - page 110, right column, line 6 see figures 2,3 --- -/--	

° Special categories of cited documents :[10]	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	
"E" earlier document but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
08 MARCH 1993	23. 03. 93
International Searching Authority	Signature of Authorized Officer
EUROPEAN PATENT OFFICE	MICHEL T.G.R.

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category°	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	JOURNAL OF VLSI SIGNAL PROCESSING vol. 1, no. 1, August 1989, DORDRECHT NL pages 57 - 67 M. ISHII ET AL 'Cellular array processor CAP and applications' see page 58, left column, line 1 - page 58, right column, line 29 see page 60, left column, line 11 - page 60, right column, line 35 see figures 1,3 . ---	1,2
A	EP,A,0 122 048 (MARTIN MARIETTA CORPORATION) 17 October 1984 see the whole document -----	1-3

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.   08/03/93

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-0122048	17-10-84	US-A- 4739474	19-04-88
		CA-A- 1201208	25-02-86
		JP-A- 59172065	28-09-84